Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 150 (2016) 1291 – 1296
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Energy Datum of the Flow of Exhaust Gases of the Internal Combustion Engine

V.A. Kozminykh[a], A.V. Raznoshinskaia[a,]*

[a] *South Ural State University, 76, Lenin Avenue, Chelyabinsk, 454080, The Russian Federation*

Abstract

The article reveals the investigation results of the energy datum of exhaust gases emitted in the atmosphere with exhaust gases of the diesel KamAZ-740 during different working modes.
The scheme and description of the experimental setup is based on the test bench DS-1036-4 / N with the utilization of the heat supply system and a set of instruments, together they allow us to determine power and economic performance of the diesel engine.
In the theoretical part of the article the following concepts are being disclosed: exhaust heat energy, exergy and the exhaust heat anergy.
The results of the tests are given in the paper. They show the changes in the indices of the exhaust gases during operation of a diesel engine KAMAZ-740 at different frequencies of a crank shaft and with different loads on the motor.
The results can be used to solve problems of exhaust gas heat utilization for further mechanical working at various recycling plants.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: internal combustion engine; diesel, exhaust gases of diesel; heat of exhaust gases; energy of exhaust gases; exergy of exhaust gases;

1. Introduction.

The most extensive use as a propulsor of track-laying and wheeled vehicles are conventional and composite engines. It is known that along with exhaust gases (EG) the great amount of energy is lost [1, 2]. In diesels the figure is equal to 85-110% in relation to effective power, in petrol engines it surpasses from 25-45%. The detected figures prove the possibility to obtain extra efficiency in case of utilization of the energy. Systems' benchmarking, capable to utilize the lost energy, revealed the viability of Sterling Engine (SE) usage [1-3]. Supplementary it is important to

* Corresponding author. Tel.: +7-951-810-24-11.
E-mail address: razn.alena1@yandex.ru

1877-7058
Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.295

know energy datum of exhaust products in each and every case emitted to the atmosphere with exhaust gases from this or that engine.

Nomenclature

m_{eg} - the mass of EG
c_{pe} - isobaric average mass specific heat capacity of EG;
H_e, H_{eg} - respectively an enthalpy of environment
ΔS - change of entropy of EG in course of warmth transfer
R_{eg} - individual gas constant of EG.
L_P - quantity of work
Ex_P - mechanical component of an exergy of EG
A_{eg} –anergy of warmth flow.

2. Experiment

Fig. 1 presents the action chart of experimental installation for energy datum research of diesel KamAZ-740.

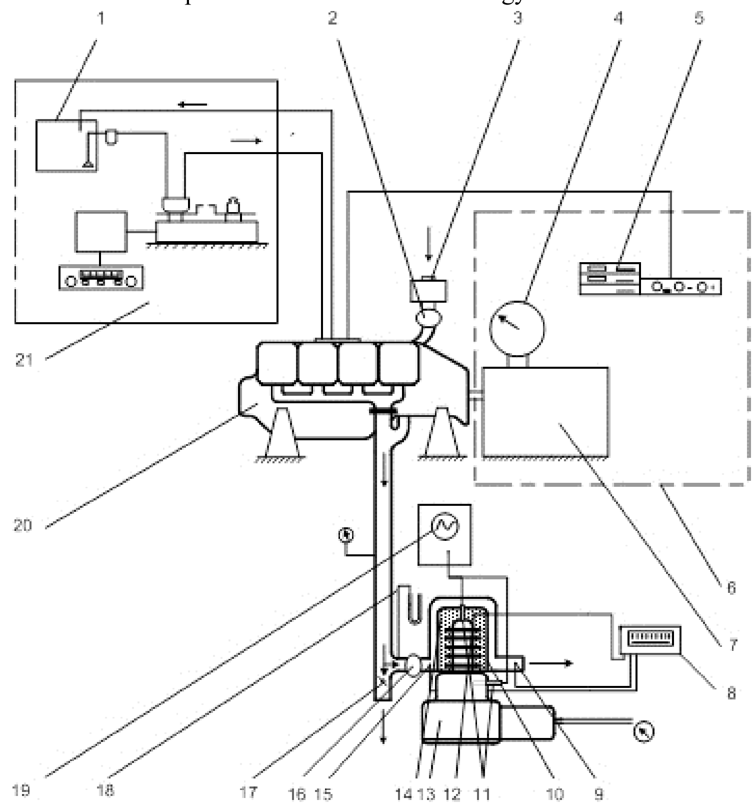

Fig. 1. the action chart of experimental installation:1 – fuel tank; 2 – air tank; 3 – gas meter of air output by diesel; 4 – weighting device of beam engine; 5 – control unit; 6 – testing set DS-1036; 7 – beam engine; 8 - potentiometer KSP-4; 9, 15 – thermal couples on the output of EG form the system of heat supply to (SE) and on the entrance; 10 – exposed wall of the temperature stabilizer ; 11 – piezoelectric sensors of cool and warm cavities of SE; 12 – thermocouple unit for temperature measurement; 13 –Stirling-electric system ; 14 – heat-retaining material; 16 –gas meter of EG consumption through the system of heat supply to SE ; 17 - valve for regulation of EG delivery in system of a warmth supply of SE; 18 – liquid level gauge; 19 - oscillograph; 20 - diesel KamAZ 740; 21 – fuel flowmeter

As pressure and temperature of EG are higher, than the corresponding parameters of environment, existence of a potential gradients are caused by a possibility of thermal and mechanical (deformation) interaction of EG with environment, i.e. a basic possibility of production of work [4-7].

The temperatures difference create a basic possibility of receiving energy derived from EG in the form of warmth (Qog) in quantity:

$$Q_{eg} = m_{eg} \cdot c_{p_{eg}} \left(T_{eg} - T_e\right) = H_{eg} - H_e, \tag{1}$$

where m_{eg} - the mass of EG; c_{pe} - isobaric average mass specific heat capacity of EG; H_{eg}, H_e - respectively an enthalpy of EG and environment.

The maximum quantity of work which can be received from this amount of heat, is defined by its exergy (a thermal exergy) [2-4,8].

$$Ex_m = m_{eg} \cdot c_{peg} \left(T_{eg} - T_e\right) - T_e \Delta S = \Delta H - T_e \Delta S == \Delta H \frac{\overline{T} - T_e}{\overline{T}} = \Delta H \cdot \tau_e, \tag{2}$$

where - the average heat dynamic temperature of cooling process of EG in environment; ΔS - change of entropy of EG in course of warmth transfer; $\tau_e = \frac{\overline{T} - T_e}{\overline{T}}$ - coefficient of operability of warmth (Carnot's coefficient) [4].

Use of a pressure difference of p_{eg} and p_e allows to receive more quantity of work (L_P) which represents a mechanical component of an exergy of EG (Ex_P). Possible that this work is possible with isothermal expansion (at a temperature of T_e):

$$L_p = Ex_p = m_{eg} R_{eg} T_e \ln \frac{p_{eg}}{p_e}, \tag{3}$$

where R_{eg} - individual gas constant of EG.

The exergy of EG also contains a chemical component (Ex_x), except thermal and mechanical. The last represents the sum of a concentration and reactionary exergy [4,9]. The concentration exergy is caused by a difference of concentration of the chemical components which are contained in EG and environment, and reactionary is connected with a possibility of working in a thermodynamic system of chemical reactions. Considering that today it is really possible to utilize only the thermal and mechanical parts of exergy, energy of EG, leaving the engine cylinder, it is possible to present the sums in the form:

$$\mathrm{E_{eg}} = \mathrm{Q_{eg}} + \mathrm{Ex_{p_{eg}}} = \mathrm{A_{eg}} + \mathrm{Ex_{\tau_{eg}}} + \mathrm{Ex_{p_{eg}}}, \tag{4}$$

where Aeg –anergy of warmth flow.

For activation of utilization SE it is possible to use only Qeg. Therefore during a pilot study the attention was paid to the thermal exergy of EG of the diesel KAMAZ-740.

It is known that the most part of time power units of mobile equipment work at the varying high-speed and load modes. Absolute value of the energy leaving cylinders EG, and their temperature significantly depend on combustion engine working modes. Obviously, as efficiency of utilization it will be essential to change as it first of all is defined by amount of heat, putting utilization SE in action. Therefore the energy of warmth flow is essentially suitable for utilization (Qeg) and a thermal exergy (power) of a warmth flow of Qeg (Exτeg) during engine operation were defined on the different modes.

3. Results

Fig. 2 displays the alteration of the specified power indicators of EG of the diesel KAMAZ-740 during its work on external high-speed and load characteristics.

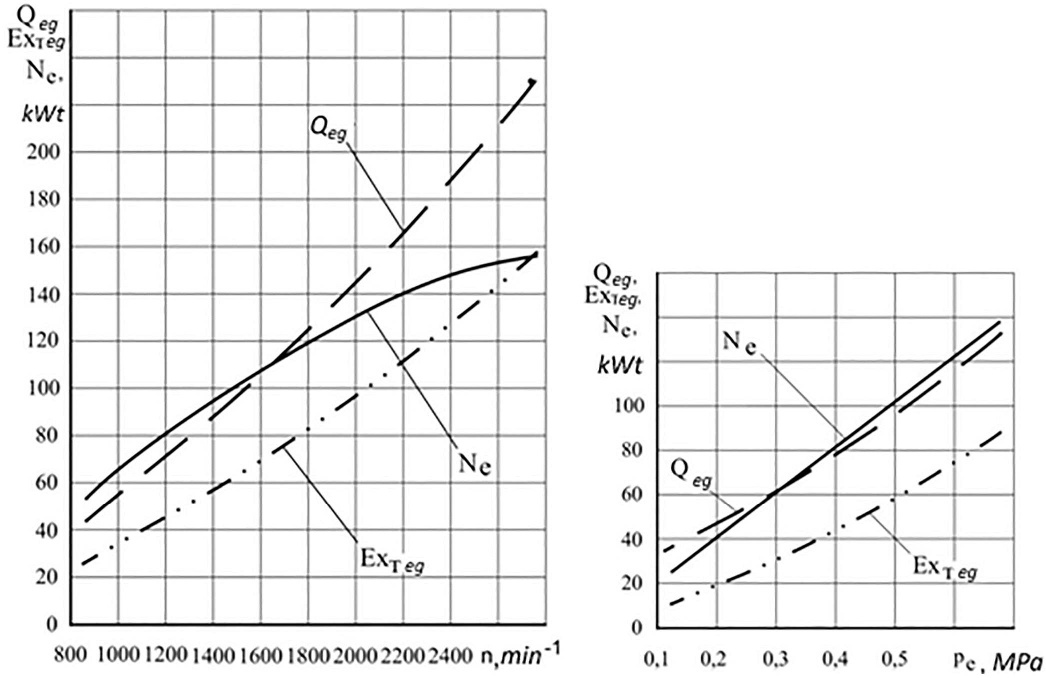

Fig. 2. Alteration of power indicators of EG during diesel work on external high-speed and load characteristics.

The analysis of these datum shows that during engine operation according to the external high-speed characteristic of warmth loss with EG there is almost always more effective power produced by the engine. Only during the diesel operation with rotating speed of the crankshaft of smaller 1500 min –1 ($\overline{n} < 0,58$) Q_{eg} is less than Ne. At rotating speed of the crankshaft, the corresponding rated power, heat losses with EG surpass effective power for 34,2%. Losses of an exergy of a warmth flow of EG practically with every frequency range of crankshaft rotation are lower than effective power. However on rated rotating speed of Exтeg is 98,1% from $N_{e_{nom}}$ Increase of rotating speed of the crankshaft leads to growth of a warmth flow of EG and its exergy (power).

Diesel operation on the load characteristic is followed by qualitatively similar variations of power indicators of EG with growth of loading. It should be noted that the warmth lost with the combustion products released into the atmosphere is slightly more than power developed by the engine only to p_e =0,3 MPa. At higher values of an average effective pressure Q_{eg} there is less N_e. Loss of an exergy with EG there is always less power developed by the diesel on average approximately for 50%.

The materials about quantity and quality of the energy lost with EG of the diesel KAMAZ-740 during the work on external high-speed and load characteristics received and considered above are useful to implementation of idea of utilization of this warmth and receiving from it to additional power. But in case it is the engine of any mobile device, then in operation it works at the many different modes. Carrying out the corresponding pilot studies has allowed to receive multiparameter characteristics of the indicators. Found in the relations of Q_{eg} and Ex_{eg} regularity (fig. 3) reflects two basic obvious facts.

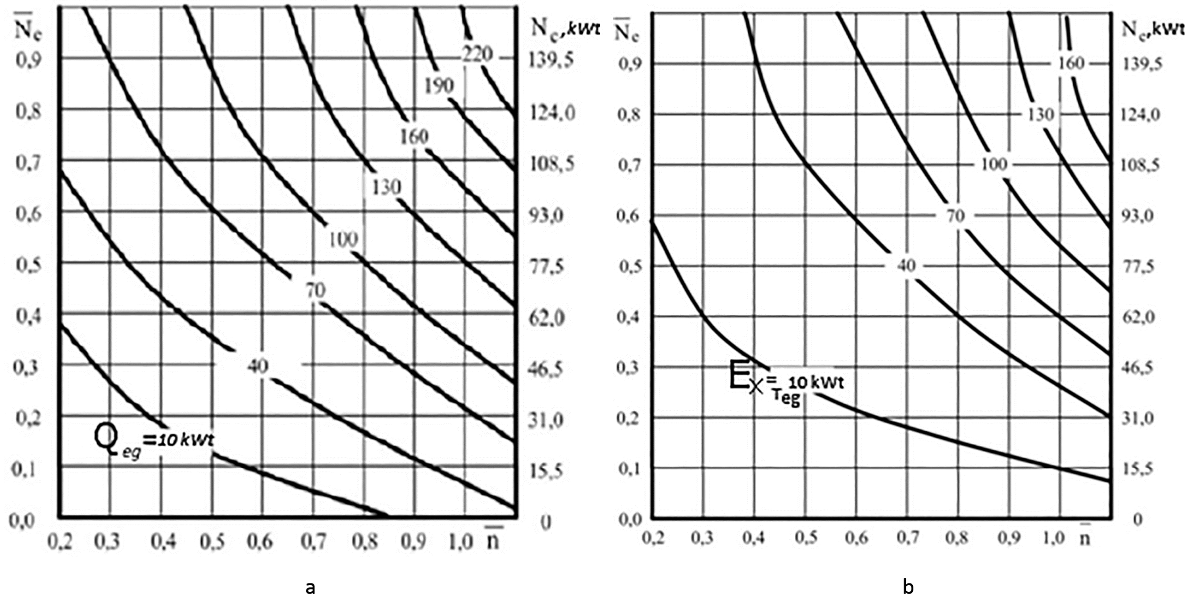

Fig. 3. Dependence of warmth (a) and thermal exergy (power) (b) EG from loading and rotating speed of the crankshaft

The heat flow released into the atmosphere with EG increases both with growth of rotating speed of the crankshaft of the engine, and with increase of loading. In the first case it is connected with the fact that growth of n leads to increase in quantity of operating cycles, and, therefore, and amounts of the gases leaving the diesel in unit of time. In the second case (with growth of loading) cyclic fuel supply increases that leads to slight increase of quantity of EG and to very noticeable increase of their temperature. Besides, the reduction of coefficient of excess of air happening at the same time increases heat capacity of combustion products.

For an assessment of the warmth flow which is taken away from EG, and its exergy (power) under operating conditions results of experiment [5] during which the engine worked at the different operational modes corresponding to operation of diesels of trucks during working modes on city and long-distance cycles [6] have been used. The taken measurements and calculations have shown that during the operation of the diesel KAMAZ-740 its average effective power (Ne) is equal in these conditions to 110,6 kWt (fig. 4).

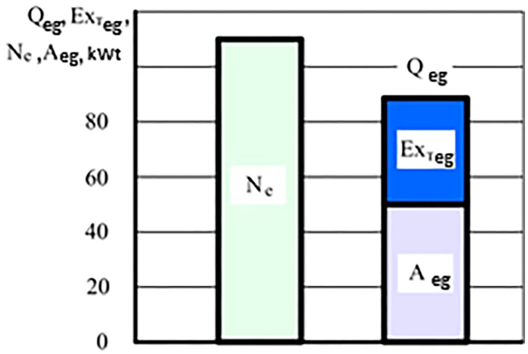

Fig. 4. Average effective power, lose warmth and a thermal exergy with the EG of KAMAZ-740 on the modes corresponding to operation of diesels of trucks during working modes in a city and long-distance cycles

Apparently, losses of warmth with EG are equal to 80,5% of Ne (89,0 kWt). At the same time the thermal exergy (power) lost with a warmth flow is 50,7 kWt (45,8% of Ne).

The lost of heat energy and a thermal exergy of EG of the diesel KAMAZ-740 during the work on external high-speed and load characteristics and on the different operational modes corresponding to operation of diesels of trucks during working modes in a city and long-distance cycles are experimentally defined.

References

[1] M.T. Zegenhagen, F. Ziegler, Feasibility analysis of an exhaust gas waste heat driven jet-ejector cooling system for charge air cooling of turbocharged gasoline engines, Applied Energy. 160 (2015) 221–230.
[2] V.S. Kukis, System-thermodynamic basis for the use of Stirling engines to improve the efficiency of power and heat plant mobile equipment Dr. diss., Chelybinsk, 1990.
[3] C. Raylene, A. Brian, Pyroelectric energy converter for harvesting waste heat: Simulations versus experiments, International Journal of Heat and Mass Transfer. 55 (2012) 4301–4311.
[4] V.M. Brodyankii, V. Fratsher, K. Mikhalek, Exergic method and its application, Energoatomizdat, Moscow, 1988.
[5] V.A. Romanov, Improving the efficiency of heat recovery of exhaust gases of ICE, Prace Tavria sovereign Agrotehnichnoy Academy. 9 (2008) 52–60.
[6] I.V. Parsadanov, Improving the quality and competitiveness of diesel engines based on an integrated fuel and environmental criteria, Kharkov, 2003.
[7] M. Hatami, M.D. Boot, D.D. Ganji, M. Gorji-Bandpy, Comparative study of different exhaust heat exchangers effect on the performance and exergy analysis of a diesel engine, Applied Thermal Engineering. 90 (2015).
[8] M. Ghazikhani, M. Hatami, D.D. Ganji, M. Gorji-Bandpy, Gh. Shahi, A. Behravan, Exergy recovery from the exhaust cooling in a DI diesel engine for BSFC reduction purposes, Energy. 65 (2014).
[9] S. Alfarawi, M. Webb-Martin, S. Mahmoud, R.K. AL-Dadah, Thermal Analysis of Stirling Engine to Power Automotive Alternator Using Heat from Exhaust Gases, Energy Procedia, Elsevier, 2014.